(12) UK Patent Application (19) GB (11) 2 340 608 (13) A

(43) Date of A Publication 23.02.2000

(21) Application No 9814012.2

(22) Date of Filing 29.06.1998

(51) INT CL[7]
G01R 33/48 , H04M 11/00 11/04

(52) UK CL (Edition R)
G1N NG48
H4K KOB KOC

(56) Documents Cited
GB 2242100 A GB 2227627 A GB 2144303 A
WO 94/03010 A1 JP 008125241 A

(58) Field of Search
UK CL (Edition Q) G1N NG28 NG48 , H4K KOB KOC
INT CL[6] G01R 33/20 33/44 33/48 , H04M 11/04
Online: WPI, JAPIO, EPODOC

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(54) Abstract Title
MRI monitoring apparatus

(57) A magnetic resonance imaging (MRI) monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system. The apparatus comprises a sensor for sensing the condition of the parameter, a signal generator arranged to generate an output signal indicative of the sensed condition of the parameter, and a telephone interface arranged for connection to a telecommunications network, and for transmission of the output signal via the telecommunications network to a remote location. The apparatus is arranged to determine if the sensed condition of the parameter is indicative of the failure or possible imminent failure of the MRI system and, upon said determination, the telephone interface is adapted to call a pr determined sequence of telephone numbers until a predetermined response is received, and then transmit the output signal. The apparatus may also be interrogated by an external user.

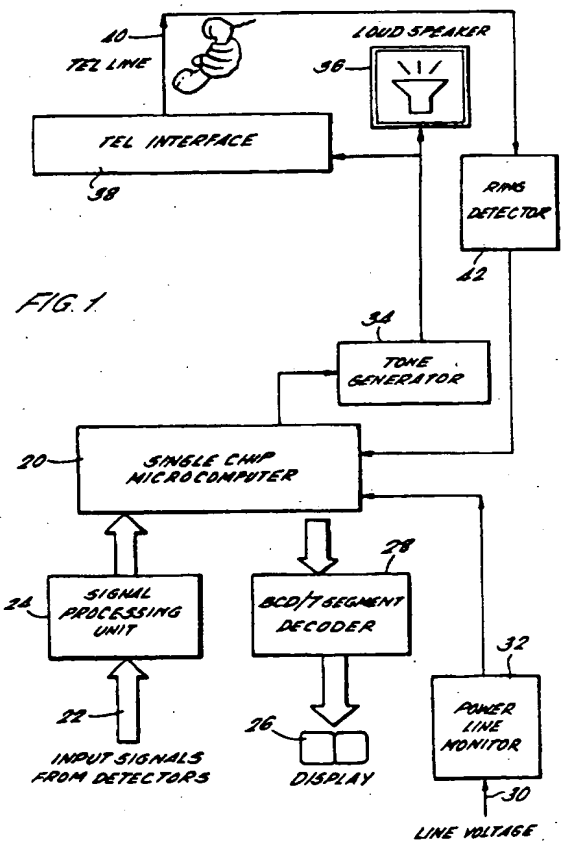

FIG. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

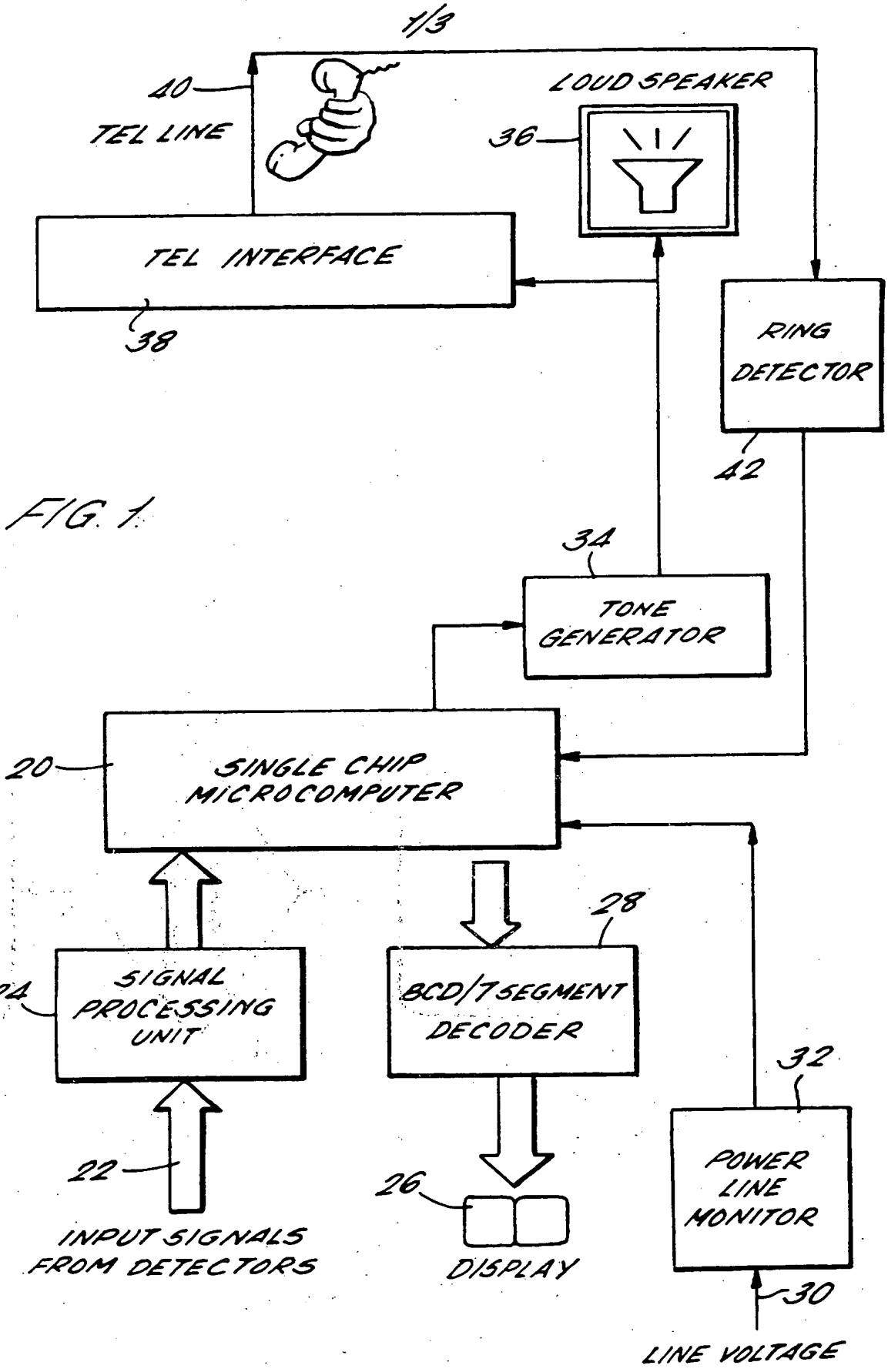
40
TEL LINE
LOUD SPEAKER
36
TEL INTERFACE
38
RING DETECTOR
42
34
TONE GENERATOR
20
SINGLE CHIP MICROCOMPUTER
28
24
SIGNAL PROCESSING UNIT
BCD/7 SEGMENT DECODER
32
POWER LINE MONITOR
22
INPUT SIGNALS FROM DETECTORS
26
DISPLAY
30
LINE VOLTAGE

FIG. 1.

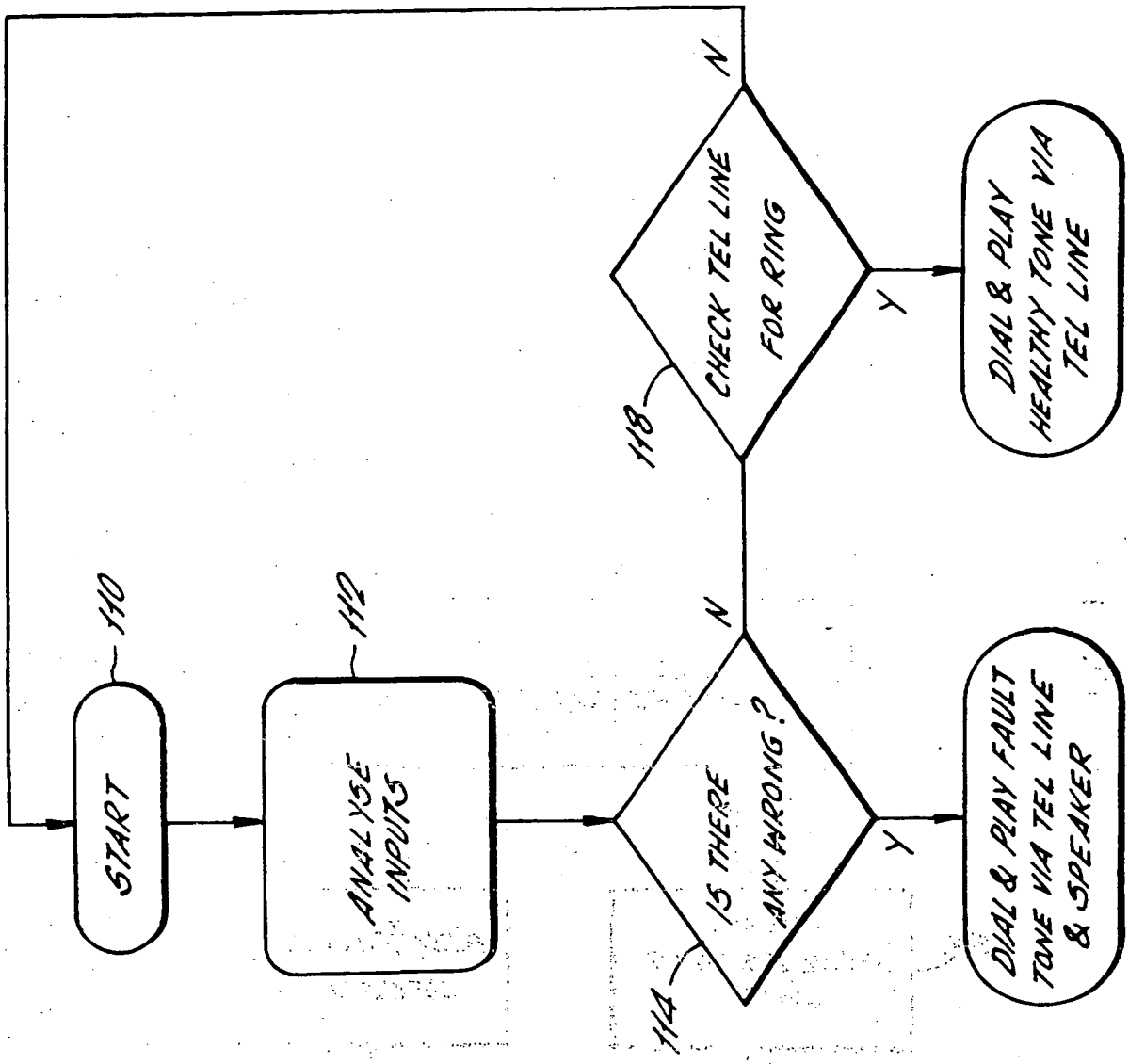
START
110
ANALYSE INPUTS
112
IS THERE ANY WRONG ?
114
N
Y
DIAL & PLAY FAULT TONE VIA TEL LINE & SPEAKER
CHECK TEL LINE FOR RING
118
N
Y
DIAL & PLAY HEALTHY TONE VIA TEL LINE

FIG. 2.

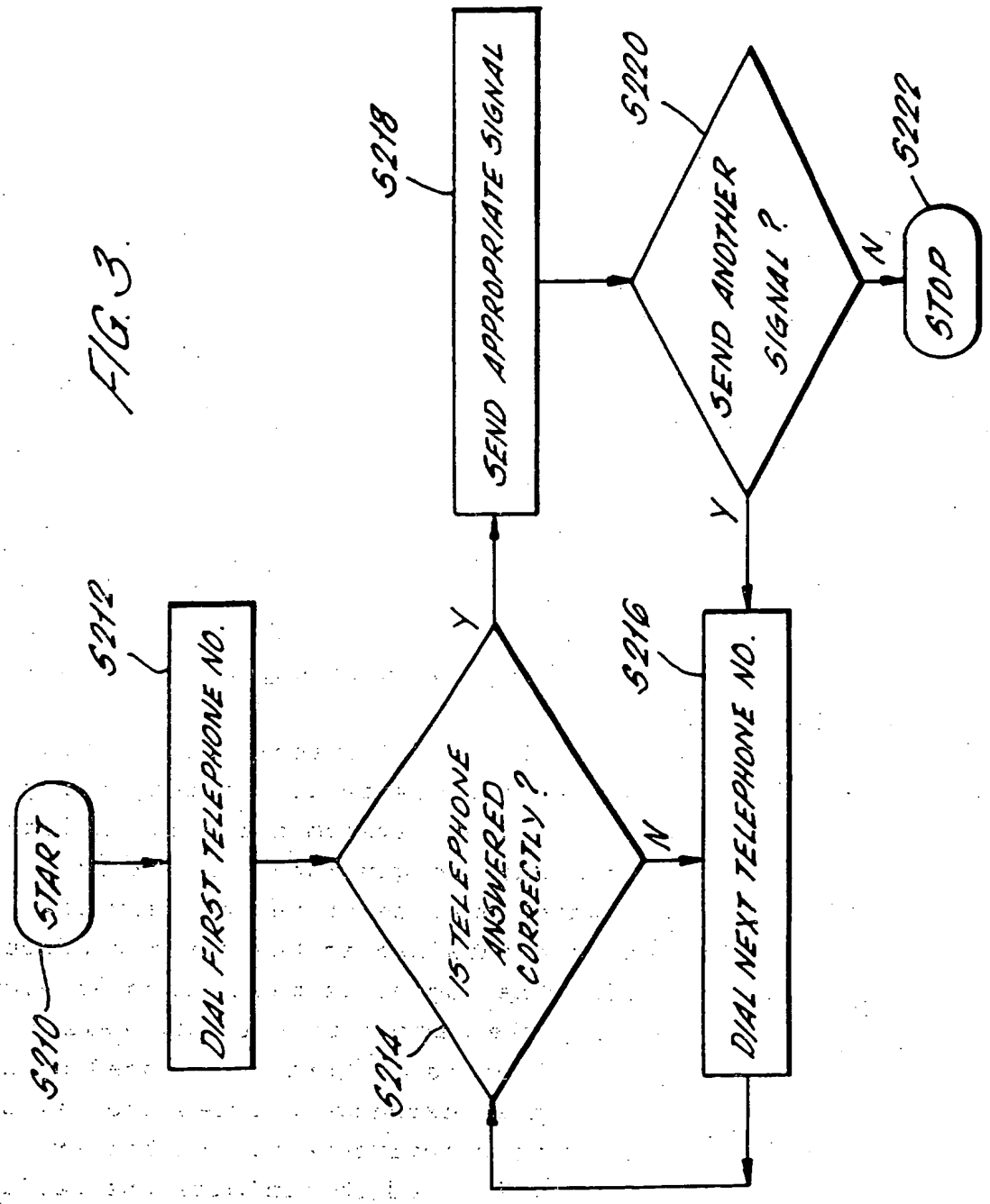
START
S210
DIAL FIRST TELEPHONE NO.
S212
IS TELEPHONE ANSWERED CORRECTLY ?
S214
Y
N
SEND APPROPRIATE SIGNAL
S218
DIAL NEXT TELEPHONE NO.
S216
SEND ANOTHER SIGNAL ?
S220
Y
N
STOP
S222

FIG. 3.

MRI MONITORING APPARATUS

The present invention relates to an apparatus for monitoring a magnetic resonance imaging (MRI) system and to a method of using an apparatus for monitoring a MRI system. In particular, the present invention relates to a monitoring system which is arranged to detect a fault in the operation of a MRI system or its environment and transmit a signal indicative of the fault to a remote user via a telecommunications network.

Magnetic resonance imaging is a technique used in medicine for producing images of soft tissues, especially in the brain and spinal cord. Based on nuclear magnetic resonance (NMR), it produces images in any plane by analysis of variations in the absorption and transmission of high frequency radio waves by tissues subjected to a strong magnetic field. The technique thus provides a non-invasive clinical imaging of the human body which enables a variety of diseases to be diagnosed without exposing a patient to x-rays.

Several parts of the MRI system must continue to operate, even whilst the system is not performing scans. For instance, a MRI system normally includes a super conducting magnet to generate the strong magnetic field, which must be stored at very low temperatures to be maintained in the super conducting state. Typically, the magnet is maintained at about -270°C by immersing the magnet in a liquid helium bath. The liquid helium is in turn surrounded by a vacuum to minimise heat exchange between the helium and the external warmer environment. A chiller (refrigeration unit) is used to minimise the boiling off of helium gas from the system.

In the event of a fault occurring in the system used to cool the magnet, the magnet may be heated by the ambient air temperature to a temperature at which the magnet is not superconducting, possibly leading to serious irreversible damage to the magnet.

Furthermore, should the helium liquid surrounding the magnet boil off (either due to a fault in the chiller unit or a leak in the helium system) then the helium which is vented from the MRI system would act to lower the partial pressure of oxygen within the surrounding air, with a consequent risk of injury to any patients or staff in or entering the surrounding area. Such a leak is particularly dangerous as helium is colourless and odourless and is consequently a difficult gas to detect except by complicated and expensive gas detection systems.

For instance, should the helium level decrease to such an extent that the magnet is no longer fully immersed in the liquid helium, the exposed region of the magnet will warm up and become non-superconducting. Once a portion of the magnet (which passes a high current) becomes non-superconducting, the resistance of that portion will become significant. This leads to a subsequent runaway ohmic heating effect as more helium liquid is boiled off from around the magnet. This effect is known as "quenching". It may result in damage to the magnet. In any event, once the magnet has been quenched, the magnet must be re-cooled and re-trained before it can be used as part of the MRI system again. Re-cooling and re-training are both expensive and time consuming.

A superconducting magnet is typically worth 40% of the total cost of the MRI system. It is therefore desirable to protect this investment during the "stand-by" time, in which the MRI unit is not in use. It is

also desirable to reduce the downtime of the system, ensuring that the system is always in a condition in which it may be used. For instance, should any problem occur in the MRI system overnight, it is desirable that the fault is identified and corrected to ensure that the system is ready for use the following working day.

It is desirable that an engineer is able to respond to any fault occurring in the system, particularly a fault in the chiller, within four hours. It is further desirable that the engineer knows the nature of the system fault before he arrives on site, in order that the engineer can ensure he has the correct tools/replacement parts to correct the fault.

In one aspect, the present invention provides a magnetic resonance imaging (MRI) monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system, the apparatus comprising a sensor for sensing the condition of said parameter, a signal generator arranged to generate an output signal indicative of the sensed condition of said parameter, and a telephone interface arranged for connection to a telecommunications network, and for transmission of said output signal via the telecommunications network to a remote location, the apparatus being arranged to determine if the sensed condition of said parameter is indicative of the failure or possible imminent failure of the MRI system and, upon said determination, the telephone interface being adapted to call a predetermined sequence of telephone numbers until a predetermined response is received, and then transmit said output signal.

The monitoring apparatus may hence periodically check (or continuously monitor) the condition of one or more parameters of the MRI system and/or the

environment of the MRI system. Such parameters might include the rate at which helium is being lost from the cooling system, the levels of helium within the system, the room temperature, the level of oxygen in the room (a low level of oxygen would indicate a possible helium leak) humidity, the power supply of the MRI, the chiller operation, the magnetic field produced by the magnet, or the signals of sensors designed to detect a fire or intrusion by an unauthorised person in the vicinity of the MRI.

If the sensed condition of the parameter indicates the failure or possible imminent failure of the MRI system then the monitoring apparatus can telephone up a systems manager or an engineer responsible for the MRI system and transmit a signal indicative of the sensed condition of the parameter. Of course, if the fault is a fire occurring or a burglary being attempted then the monitoring apparatus may be programmed to directly call the fire service or police as appropriate.

The monitoring apparatus is designed to only transmit the output signal once a predetermined response has been received. If the predetermined response is not received from the first telephone call made by the apparatus (eg. perhaps due to the telephone at the called remote location not being answered) the apparatus is adapted to continue to phone appropriate telephone numbers until the correct response is received.

Preferably, the telephone interface is further adapted to, upon said determination, call at least a second predetermined sequence of telephone numbers until a second predetermined response is received, and then transmit said output signal.

The monitoring apparatus may thus be arranged to call a predetermined sequence of telephone numbers and

leave an appropriate message on the answering of each telephone call. For instance, the monitoring apparatus may be arranged to call the home telephone number of the service engineer and, assuming that the home telephone number is only answered by an answer phone, the monitoring apparatus may leave a message on the answer phone indicating the sensed condition of the parameter and then attempt to contact the service engineer on his mobile telephone.

If it is desirable to contact two or more people (eg. if a fire has occurred or burglary is attempted then it may be desirable to inform the Police, the Fire Department, the service manager, and/or the service engineer) then the unit may be programmed to call the relevant telephone numbers and transmit an appropriate message. Different messages may be transmitted to different destinations, as appropriate.

In a further aspect, the present invention provides a magnetic resonance imaging (MRI) monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system, the apparatus comprising a sensor for sensing the condition of said parameter, a signal generator arranged to generate an output signal indicative of the sensed condition of said parameter, and a telephone interface arranged for connection to a telecommunications network, and for transmission of said output signal via the telecommunications network to a remote telephone, the telephone interface being arranged to accept an incoming telephone call from a remote user of said telecommunications network, and transmit said output signal to said remote user. A service engineer or a service manager may thus periodically check the correct functioning of the MRI system, as well as the MRI monitoring apparatus without

having to be physically present on site.

Preferably, the MRI monitoring apparatus further comprises a memory for storing the sensed condition of said parameter, the sensor being arranged to periodically sense the condition of said parameter and the signal generator being arranged to generate said output signal from said sensed condition stored in the memory.

The apparatus may thus be designed to periodically check (or alternatively,to continuously monitor) the condition of the parameter, and store this result in memory. Upon receipt of a telephone call a signal indicative of this stored condition may be transmitted to the originator of the telephone call.

Alternatively, the unit may be designed to only sense the condition of the parameter upon the receipt of a telephone call.

Preferably, the MRI monitoring apparatus is further arranged to be reprogrammed by appropriate signals received by said telephone interface from said telecommunications network.

In this way, the monitoring apparatus may be easily programmed to operate in any desired manner from a remote location. For instance, it may be desirable to alter the sequence of predetermined telephone numbers to be called due to a person or service being unavailable or relocated.

In a further aspect, the present invention provides a method of operating a magnetic resonance imaging (MRI) system comprising the steps of: sensing the condition of a parameter of at least one of an MRI system and the environment of the MRI system; determining if said sensed condition is indicative of the failure or possible imminent failure of the MRI system; and upon said determination, automatically

calling a predetermined sequence of telephone numbers until a predetermined response is received, whereupon an output signal indicative of the sensed condition of said parameter is automatically generated and transmitted, via a telecommunications network, to a remote location.

Preferably, the predetermined response is a person answering a telephone call at the remote location. The predetermined response might include the transmission of a code word or sequence. In some circumstances only, it may be undesirable for the MRI system to leave a signal indicating the sensed condition of the parameter on an answer phone. Instead, it may be desirable for the apparatus to continue to call the predetermined sequence of telephone numbers until it may transmit a signal to an appropriate person.

In a further aspect, the present invention provides a method of operating a magnetic resonance imaging (MRI) system comprising the steps of: automatically accepting an incoming telephone call from a remote user of a telecommunications network; sensing the condition of a parameter of at least one of an MRI system and the environment of the MRI system; generating an output signal indicative of the sensed condition of said parameter; and transmitting said output signal to the remote user.

Preferably, the transmission of the output signal to a remote user only occurs if the remote user has previously provided a predetermined identification signal e.g. a code. This ensures that only authorised personnel may determine whether or not the MRI system is operating correctly.

A preferred example of the invention will now be described with reference to the figures, in which

Figure 1 is a block diagram of an apparatus

according to a first embodiment of the present invention,

Figure 2 is a flow chart indicating the operation of the apparatus shown in Figure 1, and

Figure 3 is a flow chart indicating a preferred mode of the step 116 shown in Figure 2.

In Figure 1, a MRI monitoring apparatus includes a single chip microcomputer 20, such as an 80C31 micro controller, for controlling the operation of the monitoring apparatus. The apparatus is powered by the same line voltage 30 that powers the MRI system. Additionally, the monitoring apparatus has a backup power supply (not shown). A power line monitor 32 continuously sensors the line voltage 30 and outputs a logic level signal to the single chip microcomputer 20 indicative of the measured line voltage.

Various sensors/detectors (not shown) monitor other parameters of the MRI system and the environment of the MRI system. These sensors transmit input signals 22 to a signal processing unit 24. The signal processing unit 24 converts the signals from the various sensors to digital logic levels, the resulting digital signals being transmitted to the input buffer of the microcomputer 20.

A third input to the microcomputer 20 is from a ring detector 42. The ring detector 42 is connected to a telecommunications network 40 via a normal telephone line. The ring detector 42 detects incoming telephone calls from the telecommunications network 40.

The various operational states of the apparatus may be indicated on the display 26 which in this particular embodiment is connected to an output of the microcomputer 20 via a BCD/7 segment decoder 28.

The microcomputer 20 controls the operation of a signal generator. In this particular embodiment the

signal generator is a tone generator 34, which may be a 555 timer arranged to operate as an astable multivibrator. The output of the tone generator 34 is connected to both a loudspeaker 36 and a telephone interface 38. The telephone interface 38 is in turn connected to the telecommunications network 40.

The loudspeaker 36 produces an audible signal at the MRI system site based upon the output signal from the tone generator, whilst the telephone interface 38 may be used to transmit this signal via the telecommunications network 40 to a remote location.

In Figure 2, the monitoring apparatus normally begins operation at the start step 110 by the microcomputer 20 checking the values of the various sensed conditions by reading the various signals sent to the microcomputer input buffer. The microcomputer will then analyse these signals (step 112) to determine if there is a fault or possible impending fault in the MRI system or its environment (step 114).

This analysis of the input signals (step 112) may be the determination of whether the signals are within predetermined boundary conditions. Such boundary conditions may be progressive eg. the microcomputer may continuously monitor the level of oxygen in the room in which the MRI system is located (normally, atmospheric oxygen concentration is 18-21%), with a fault condition being determined if the oxygen concentration appears to be significantly decreasing (i.e. indicative of a helium leak).

If step 114 determines that there is no fault occurring or likely to occur, then the microcomputer checks the condition of the ring detector 42 (step 118) to determine if there is an incoming call from the telecommunications network.

If there is no incoming telephone call from the

telecommunications network, then the monitoring apparatus proceeds back to the initial step 110.

However, if at step 118 the microcomputer determines that there is an incoming telephone call, the microcomputer 20 instructs the telephone interface 38 to answer the incoming telephone call and for the tone generator 34 to generate and transmit via the telephone interface a tone indicating that the MRI and its environment are operating without any faults (step 120).

However, if at step 114 the microcomputer 20 detects a possible fault condition, then the microcomputer 20 instructs the telephone interface 38 to transmit an appropriate output signal to a remote location (step 116). The telephone interface 38 then commences dialling the first of a predetermined sequence of telephone numbers. The telephone interface continues to dial this predetermined sequence of telephone numbers until it receives a predetermined response, such as the telephone being answered. The microcomputer 20 instructs the tone generator 34 to generate and transmit, via the telephone interface, a signal indicating the faulty condition. The exact signal transmitted may be dependent upon the type of fault that has been detected.

Figure 3 shows a preferred embodiment of the step 116, in which the telephone interface may transmit a number of appropriate signals to various remote locations.

In this preferred embodiment, if it is determined at step 114 that there is a fault occurring or likely to occur within the MRI system or its environment, then the telephone interface begins the sequence of steps (S210) shown in Figure 3. The telephone interface dials the first telephone number within the programmed

predetermined sequence (S212). The telephone interface then checks if this telephone call is answered, and if it is answered whether it is correctly answered in a predetermined manner (S214).

If the telephone is not answered correctly then the telephone interface 38 dials the next telephone number in the predetermined sequence (S216). If all the telephone numbers within that particular predetermined sequence have been dialled, then the telephone interface may re-iterate through the predetermined sequence once again.

Once the next appropriate number has been dialled, the telephone interface then jumps back to step S214 to check whether this next number that has been dialled has been answered correctly.

If a remote telephone call is answered correctly (S214), the telephone interface proceeds to step S218 and transmits an appropriate signal to the remote telephone (or modem).

The telephone interface then checks whether it has been programmed to send any more signals (S220.

If the telephone interface has been programmed to send one or more further signals then the next appropriate telephone number is dialled (S216). This next appropriate telephone number may be the next telephone number within that first predetermined sequence, or else it may be the first of a second predetermined sequence of telephone numbers.

The telephone modem then iterates around the steps S214, S216, S218 and S220 until it is determined that no further telephone calls should be made (step S222).

At this point, the monitoring apparatus may then stop operation. Alternatively, the monitoring apparatus may be programmed to re-enter the loop defined by steps 114, 118, 110 and 112 to determine if any further

faults occur within the MRI or its environment, and to signal such faults to any predetermined remote locations as appropriate.

Depending how the monitoring apparatus has been programmed, the predetermined response may either be the telephone call being answered, or by the telephone call being answered and a correct signal being transmitted from the remote location. The correct signal may be an identification code or the recognition of the person answering using voice or speech recognition techniques to identify either the answering person or a sequence of words spoken by the answering person.

The monitoring apparatus may thus be used to remotely monitor MRI systems around the clock, even whilst the MRI systems are unattended eg. in the evenings and at weekends.

In a particular preferred embodiment, the monitoring apparatus is arranged to monitor thirty parameters of the MRI system and its environment. However it will be appreciated that the apparatus may be arranged to monitor any desired number of conditions of any single MRI system and its environment, or even any number of MRI systems at different sites.

For instance, several MRI systems could be monitored via cascaded monitoring systems. In this event, a 'slave' monitoring system is installed on each MRI unit which can send and receive data via a modem to the central 'master' monitoring system, which could in turn be monitored around the clock. When a problem occurs within any of the MRI units being monitored the relevant MRI unit would be identified by its own unique code. This system would therefore be most useful to companies wishing to monitor several units, either fixed or mobile, or for a maintenance organisation

owning or servicing several units.

The monitoring apparatus can monitor any variety of sensed parameters relating to MRI systems such as room temperature, humidity, power failure, chiller operation, magnetic field strength, helium leakage, fire and intrusion.

Although in the particular embodiment described the monitoring apparatus simply generates a tone indicative of the performance of the MRI system as an output signal, it will be appreciated that the output signal may be in other forms. For instance, the output signal may be a unique code or voice message.

In a particular preferred embodiment, the signal generator is a voice generator, such as a single chip voice recorder/play back device ISD 14xx series, with signals output to a loudspeaker and/or a telephone interface. Voice messages indicative of the sensed condition of the MRI and its environment may then be output in an appropriate language (or languages) for the service engineer, MRI operator staff and/or patients to comprehend.

The output signal may contain information indicating not only the condition of the fault detected, but also identifying the precise location of the MRI system, (e.g. by an identification code unique to the respective MRI system) as well as indicating the history of the sensed parameters.

Although the monitoring apparatus has been described in conjunction with a magnetic resonance imaging system, it will be appreciated that the monitoring apparatus may be used to monitor the condition of any other hi-tech medical imaging system which operates continuously eg. Bio-magnetic imaging systems.

CLAIMS

1. A magnetic resonance imaging (MRI) monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system, the apparatus comprising

a sensor for sensing the condition of said parameter,

a signal generator arranged to generate an output signal indicative of the sensed condition of said parameter, and

a telephone interface arranged for connection to a telecommunications network, and for transmission of said output signal via the telecommunications network to a remote location,

the apparatus being arranged to determine if the sensed condition of said parameter is indicative of the failure or possible imminent failure of the MRI system and, upon said determination, the telephone interface being adapted to call a predetermined sequence of telephone numbers until a predetermined response is received, and then transmit said output signal.

2. A MRI monitoring apparatus as claimed in Claim 1, wherein the telephone interface is further adapted to, upon said determination, call at least a second predetermined sequence of telephone numbers until a second predetermined response is received, and then transmit said output signal.

3. A magnetic resonance imaging (MRI) monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system, the apparatus comprising

a sensor for sensing the condition of said

parameter,

a signal generator arranged to generate an output signal indicative of the sensed condition of said parameter, and

a telephone interface arranged for connection to a telecommunications network, and for transmission of said output signal via the telecommunications network to a remote telephone,

the telephone interface being arranged to accept an incoming telephone call from a remote user of said telecommunications network, and transmit said output signal to said remote user.

4. A MRI monitoring apparatus as claimed in Claim 3, further comprising a memory for storing the sensed condition of said parameter, the sensor being arranged to periodically sense the condition of said parameter and the signal generator being arranged to generate said output signal from said sensed condition stored in the memory.

5. A MRI monitoring apparatus as claimed in any of the above claims, wherein the apparatus is further arranged to be reprogrammed by appropriate signals received by said telephone interface from said telecommunications network.

6. A MRI monitoring apparatus as claimed in any of the above claims, wherein said signal generator is arranged to generate a speech output signal indicative of the sensed condition of said parameter.

7. A method of operating a magnetic resonance imaging (MRI) system comprising the steps of:

sensing the condition of a parameter of at least

one of an MRI system and the environment of the MRI system; determining if said sensed condition is indicative of the failure or possible imminent failure of the MRI system; and

upon said determination, automatically calling a predetermined sequence of telephone numbers until a predetermined response is received, whereupon an output signal indicative of the sensed condition of said parameter is automatically generated and transmitted, via a telecommunications network, to a remote location.

8. A method of operating a MRI system as claimed in Claim 7, wherein said predetermined response is a person answering a telephone at said remote location.

9. A method of operating a MRI system as claimed in Claim 7 or Claim 8, further comprising the steps of:

upon said determination, automatically calling a second predetermined sequence of telephone numbers until a second predetermined response is received, whereupon a second output signal indicative of the sensed condition of said parameter is automatically generated and transmitted, via a telecommunications network, to a second remote location.

10. A method of operating a MRI system as claimed in Claim 7, Claim 8 or Claim 9, wherein said output signal includes information indicative of the location of the MRI system.

11. A method of operating a magnetic resonance imaging (MRI) system comprising the steps of:

automatically accepting an incoming telephone call from a remote user of a telecommunications network;

sensing the condition of a parameter of at least

one of an MRI system and the environment of the MRI system;

generating an output signal indicative of the sensed condition of said parameter; and

transmitting said output signal to the remote user.

12. A method of operating a MRI system as claimed in Claim 11, said transmission of the output signal to a remote user only occurs if said remote user has previously provided a predetermined identification signal.

13. A magnetic resonance imaging monitoring apparatus for monitoring a parameter of at least one of an MRI system and the environment of the MRI system substantially as herein described in reference to the accompanying drawings.

14. A method of operating a magnetic resonance imaging system substantially as herein described with reference to the accompanying drawings.

15. A magnetic resonance imaging system including a magnetic resonance imaging monitoring apparatus substantially as herein described with reference to the accompanying drawings.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 9814012.2 **Examiner:** Peter Emerson
Claims searched: 1-15 **Date of search:** 14 December 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1N NG48, NG28; H4K KOB, KOC

Int Cl (Ed.6): G01R 33/20, 33/44, 33/48; H04M 11/04

Other: Online: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2227627 A	(DICTAPHONE) engineers + number sequence	1, 6-8
Y	GB 2242100 A	(TUNSTALL) transmit + interrogate	1, 3-5, 7, 11, 12
Y	GB 2144303 A	(REMOTE) interrogate	3, 4, 11
Y	WO 94/03010 A1	(AUTOMATED) MRI + telephone	1, 3-8, 11, 12
Y	JP 08 125241 A	(HITACHI) - leak detection see PAJ abstract	1, 3-8, 11, 12

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.